Carbon-14

Symbol:	**C(-14)**
Atomic Number: *(protons in nucleus)*	**6**
Atomic Weight: *(naturally occurring)*	**12**

What Is It? Carbon-14 is a naturally occurring radioactive isotope of carbon. (An isotope is a different form of an element that has the same number of protons in the nucleus but a different number of neutrons.) Carbon is widely distributed in nature and is present in all organic compounds. Natural forms include diamonds and graphite, which are among the hardest and softest minerals known, respectively. The nucleus of a carbon-14 atom contains six protons and eight neutrons. There are two stable (nonradioactive) isotopes of carbon: carbon-12, which has six protons and six neutrons, and carbon-13, which has six protons and seven neutrons. Carbon-12 comprises most (about 99%) of naturally occurring carbon, and carbon-13 accounts for about 1.1%. Naturally occurring carbon contains an extremely small fraction (about two trillionths) of radioactive carbon-14.

There are several radioactive isotopes of carbon in addition to carbon-14. These isotopes are very short-lived – with half-lives ranging from 20 minutes for carbon-11 to less than a second – so they are not a health concern for Department of Energy (DOE) environmental management sites. The half-life of carbon-14 is about 5,700 years, and it decays by emitting a beta particle with no attendant gamma radiation to produce nitrogen-14. Carbon-14 is an important radionuclide in the low-level radioactive wastes previously disposed of at Hanford.

Radioactive Properties of Carbon-14

Isotope	Half-Life *(yr)*	Natural Abundance *(%)*	Specific Activity *(Ci/g)*	Decay Mode	Radiation Energy *(MeV)*		
					Alpha *(α)*	Beta *(β)*	Gamma *(γ)*
C-14	5,700	0.2 billionth	4.5	β	-	0.049	-

Ci = curie, g = gram, and MeV = million electron volts; a dash means that the entry is not applicable. (See the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for explanation of terms and interpretation of radiation energies.) Values are given to two significant figures.

Where Does It Come From? Carbon-14 is produced naturally in the upper atmosphere by the reaction of neutrons originating from cosmic rays with nitrogen and, to a lesser extent, with oxygen and carbon. The natural steady-state inventory of carbon-14 in the biosphere is about 300 million Ci, most of which is in the oceans. Large amounts of carbon-14 have also been released to the atmosphere as a result of nuclear weapons testing. Weapons testing through 1963 added about 9.6 million Ci, an increase of 3% above natural steady-state levels. Carbon-14 is also made commercially for use in medical or biological tracer research. Carbon-14 is produced in nuclear reactors by the capture of neutrons by nitrogen, carbon, or oxygen present as components of the fuel, moderator, or structural hardware. The contribution to the carbon-14 global inventory from commercial nuclear reactors and DOE facilities in the United States has been less than 600 Ci per year, or less than 1/500,000th of the natural steady-state level. Carbon-14 was produced at Hanford by neutron activation of carbon in graphite-moderated plutonium-production reactors in the 100 Area. Carbon-14 is present in the graphite moderator of these shutdown reactors and in certain wastes associated with previous reactor operations, as well as in wastes from ongoing decommissioning activities, including for spent graphite.

How Is It Used? Two main uses of carbon-14 are in diagnostic medical procedures and radiocarbon dating to determine the age of previously living animals and plants. In medicine, carbon-14 can be injected to study abnormalities of metabolism that underlie diabetes, gout, anemia, and acromegaly (adult "gigantism"), and to trace the metabolism of new drugs. However, its main use to date has been to determine the age of fossils and other dead organic material. All living organisms absorb carbon from the environment, which contains carbon-12 and carbon-14 in a fixed ratio. When an organism dies, it no longer takes in carbon through respiration so the amount of carbon-14 will decrease at a constant rate due to radioactive decay, resulting in a lower ratio of carbon-14 to carbon-12 over time. Because this is constant in all living organisms, one can determine when an organism died by measuring the ratio of these two isotopes. Radiocarbon dating is considered one of the most reliable means of determining the age of artifacts containing plant or animal matter, including some prehistoric materials up to 50,000 years old.

What's in the Environment? Carbon-14 is present in the atmosphere, oceans, and all organic material, and it behaves in the environment in the same manner as other carbon isotopes. The largest source is in the upper atmosphere where nitrogen interacts with neutrons from cosmic rays, with about 38,000 Ci of carbon-14 being produced by this process each year. The atmospheric inventory is estimated at 13 million Ci, and it is generally present as carbon dioxide with less than 1% in the form of carbon monoxide, methane, formaldehyde, and other molecules. Carbon-14 distributes throughout the atmosphere and surface ocean waters over a period of several years. Transfer to deep ocean waters proceeds much more slowly, taking hundreds to thousands of years. The carbon-14 concentration in the troposphere has been reported to be 3.4 pCi per kilogram of air, and its concentration in soil is about 0.2 pCi/g. Carbon-14 occurs in the ratio of 6 picocuries (pCi) of carbon-14 per gram of total carbon, and it is assimilated into tissues of all plants and animals just like other carbon isotopes. Carbon-14 is present at Hanford as a contaminant associated with graphite-moderated reactors. It is not a major contaminant in site groundwater due to its low leachability from graphite waste and limited presence in soil. Concentrations in sandy soil are estimated to be 5 times higher than in the interstitial water (in the pore spaces between the soil particles). Thus, carbon-14 that does leach from solids to soil can move downward fairly quickly with percolating water to groundwater.

What Happens to It in the Body? Carbon-14 can be taken into the body by drinking water, eating food, or breathing air. Carbon-14 is present in the human body at a level of about 1 microcurie (or 1 million pCi) in adults, and it behaves in the same manner as other carbon isotopes. Most carbon-14 is almost completely absorbed upon ingestion, moving quickly from the gastrointestinal tract to the bloodstream. However, some carbon-containing compounds in food, such as cholesterol, fat-soluble vitamins, cellulose, and polysaccharides, may be less completely absorbed. The fractional uptake of carbon-14 by inhalation is strongly dependent on its chemical form. For carbon dioxide gas and organic compounds, essentially all inhaled carbon-14 is absorbed into the bloodstream, while for carbon monoxide gas the absorption fraction is about 40%. The absorption fraction for carbon-14 on inorganic particulate aerosols is significantly lower. The carbon-14 that enters the bloodstream after either ingestion or inhalation is quickly distributed to all organs and tissues of the body, as for other isotopes of carbon. Carbon-14 is eliminated from the body with a biological half-life of 40 days.

What Is the Primary Health Effect? Carbon-14 poses a health hazard only if it is taken into the body, because it decays by emitting a weak beta particle with no gamma radiation. The beta particle emitted by carbon-14 has low energy and cannot penetrate deeply into tissue or travel far in air. Carbon-14 behaves the same as ordinary carbon, both in the environment and in the human body. Hence, a significant fraction of the carbon-14 taken in by either ingestion or inhalation is absorbed into the bloodstream, where it is transferred to all organs of the body. The health hazard of carbon-14 is associated with cell damage caused by the ionizing radiation that results from radioactive decay, with the potential for subsequent cancer induction.

Radiological Risk Coefficients

This table provides selected risk coefficients for inhalation and ingestion. The recommended default absorption type was used for inhalation as an organic particulate, and the dietary value was used for ingestion. Risks are for lifetime cancer mortality per unit intake (pCi), averaged over all ages and both genders (10^{-12} is a trillionth). Other values, including for morbidity, are also available.

Isotope	Lifetime Cancer Mortality Risk	
	Inhalation (pCi^{-1})	**Ingestion** (pCi^{-1})
Carbon-14	6.5×10^{-12}	1.4×10^{-12}

For more information, see the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients and the accompanying Table 1.

What Is the Risk? Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including carbon-14 *(see box at right).* Additional values are also available, including for inhalation of carbon-14 as a gaseous oxide, i.e., as carbon monoxide and carbon dioxide. As for other radionuclides, the risk coefficient for tap water is about 80% of that for dietary ingestion.